REDWOOD SPROUT REGENERATION AFTER THINNING
40 YEAR OLD STANDS

JAMES L. LINDQUIST RPF #661

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Introduction

Partial logging of the coastal redwood/Douglas-fir type since the early 1960's has left thousands of acres with multi-level canopies. Before the next entry managerial decisions are now required whether to continue the tree selection process or remove the entire overstory and re-establish an evenage structure. Intensity of the original cut may have a significiant effect on the degree and type of regeneration that became established in the understory. Evidence from the Jackson Demonstration State Forest's (JDSF) Caspar Creek Cutting Trials suggests that redwood and Douglas-fir growth and regeneration has not been too successful when tree selection logging removed 40-50 percent of an 85-year old stand (Lindquist,1986).

Study objectives

Another study of the effect of canopy on regeneration of these valuable stands is the Whiskey Springs commercial thinning experiment of 40-year old well-stocked redwood stands. The Whiskey Springs commercial thinning study was established in 1970 as a joint project of the U.S. Forest Service's PSW Experiment Station and California Department of Forestry. Intent of this thinning study, designed by Rudy Strothmann, retired USFS research forester, was to evaluate growth and yield of well-stocked 30-40 year old redwood stands after a commercial thin. The Whiskey Springs study on the JDSF is one of three sets of 12 plots with three replicated treatments and control plots. Treatment removed 25,50, and 75 percent of the plot's original basal area. Treatments were assigned at random to twelve four--tenth acre plots, three plots for each thinning level and contol. Plots averaged 40 years old, 400 square feet of basal area, nearly all were redwood. Residual stands after thinning had 100,200, and 300 sq.ft. of basal area.

A second study started in 1972 took advantage of the earlier plot work to look at the amount of sprouting under the three overstory levels. A report that described the sampling and initial sprout populations was made in 1979 (Lindquist,1979). Plot maps of the stumps and trees were an important feature of the work. Maps identify, record, and locate the sprout clumps two growing seasons after logging.

The objective of this report, a follow-up of the 1972 study, is to report the number of established sprouts on each mapped stump. An important silvicultural consequence of logging is the number and size of established sprouts. A study of sampling this sprout regeneration suggested that at least one established sprout per clump is a reasonable assumption of the sprout regeneration (Lindquist,1974). Results of the 1986 examination, after 15 years of growth, are used to examine the validity of this assumption. The level of regrowth will influence additional silvicultural activity. Effects of the overstory on sprout growth is an important part of partial logging's silvicultural future of further management activity in these stands.

1972 study

Maps were made of six thinned plots, all control plots were mapped but no sprouts were found. All trees and stumps in the 132 foot square plots were mapped and located by horizontal and vertical distance from the northwest corner of each plot. Explanation of the methods and results of the 1972 field work is covered in published report (Lindquist, 1979). Recorded data for each stump or tree was: species, diameter, stump height, height of tallest sprout, and the number of clumps and sprouts. A summary of the plots 1972 initial conditions is shown in Table 1. Strothmann's thinning work tagged the central .2 acre, the buffer (.2 acre) was treated as the tagged portion. Only stems larger than 4.5 inches DBH were reported by Strothmann, but in the 1972 study all stumps down to one inch were mapped. Intent of mapping was to record all locations where sprouts occurred. Maps would help resolve problems of deciding a tree's origin, seedling or sprout. Many mapped sprouts were on small whip-like stems less than an inch in diameter. Stumps as large as 5 or 6 inches may not be visable in 15 years. Differences in the number of stumps between 1970 and 1972 studies is accounted for by trees less than 4.5 inches in diameter at breast-height. Diameter distributions of stumps less than the 5 inch class of the six mapped plots averaged 125 stumps, and most small stumps sprout. These plots averaged 1140 clumps and 5795 sprouts per acre in 1972.

Stocking of milacre and 4-milacre quadrats in the mapped plots was reported in the 1979 report. Stocked quadrats shown in Table 2 for the 100 percent coverage of the mapped plots was 30.0 percent of the milacre and 66.3 percent of the 4-milacre quadrats had sprouts. Lowest stocking was 23.5 and 57.0 percent in plot 4 of the 75% residual. Milacre sprout stocking reported here is much more than the 7 percent reported after logging of old-growth (Person and Hallin, 1942). This study looks at the generation of redwood sprouts following harvest of second growth. The maintenance of stocking percentages over the period is an important feature of this study. Quadrats stocked with sprouts have a greater degree of importance to the eventual stand structure than those stocked with 1 or 2 year old seedlings. There is greater permanance when redwood sprouts occupy a quadrat, and established sprouts at 15 years have more value than clumps at 2 years old.

The 1986 study

Table 1. Descriptive values of the cut and residual stands of six mapped Whiskey Springs thinned plots. Values for the stand over 4.5 inches DBH from 1970 results at the plot establishment in 1970. The 1972 values reflect all stems mapped in 1972. All values are on an acre basis.

Plot	1970 results Trees BA	Trees trees	Trees dia.	Stumps BA	Stumps trees	Stumps dia.	1972 results Stumps stumps	Stumps clps.	Stumps spts
	(sqft)		(in)	(sqft)		(in)			
1	102	45	20.4	282	255	12.5	293	980	4980
6	100	50	19.1	248	505	9.5	782	2068	10550
8	99	40	21.3	316	375	12.4	422	1184	6977
9	201	90	20.2	232	300	11.9	430	1022	4360
10	201	150	15.7	206	285	11.5	408	968	5705
4	301	230	15.5	87	225	8.4	332	615	2200

Table 2. Stocking of clumps on milacre and 4-milacre plots in the 1972 mapping of Whiskey Springs thinned plots, and sprout stocking in 1986. All plots in these four-tenth acre plots are shown, 100 4-milacre and 400 milacre.

Plot	1972 results clmps	milacre	4-milacre	1986 results sprts.	milacre	4-milacre
		(prct)	(prct)		(prct)	(prct)
1	980	24.0	61.0	1250	22.0	60.0
6	2068	45.5	82.0	2320	42.5	81.0
8	1184	29.7	65.0	1602	28.2	66.0
9	1022	28.7	71.0	930	21.7	67.0
10	968	28.5	62.0	1132	22.0	60.0
4	615	23.5	57.0	88	3.5	17.0

Between the 1972 study and the 1986 resurvey the study of the growth and yield of the thinned overstory has continued. Remeasurements of residual trees were made in 1975,1980, and 1985. During this time it was evident that a dense aggressive sprout population was growing rapidly under the 25% and 50% residual canopies. Under the 75% treatment the sprouts did not show a growth rate or stem form consistent with the vigor shown in the initial survey in 1972. A reinventory of the sprouts was considered since it was apparent that some thinning might be needed in the sprout understory of 25% and 50% treatments. Stem and stump maps were used to relocate each of the stumps on the mapped thinned plots. A tally of all live sprouts taller than 4.5 feet on each stump was done. Similar surveys were made on the three thinned plots that had not been mapped. Sprouts were tallied by diameter at breast height into size classes as: < .5, 1,2,3,4,5, and >5.5 inches. At least one and as many as three sprouts per stump had the diameter at breast height and total height measured and recorded. Number of sprouts per acre for seven diameter size classes and all nine thinned plots are shown in Table 3.

Results of remeasurement

Sprouting response of redwood to a clear cut is perhaps different than that after partial cutting or thinning. Biological control of residual redwood trees on the sprout response of associated stumps, and the overstory control of light and space are both operating in partially cut stands. The first item of interest is whether the overstory canopy and stump diameter affects the number and size of sprouts established in the plots. A second interest is to determine if it is possible to develop a process to predict sprout stocking prior to cutting a stand.

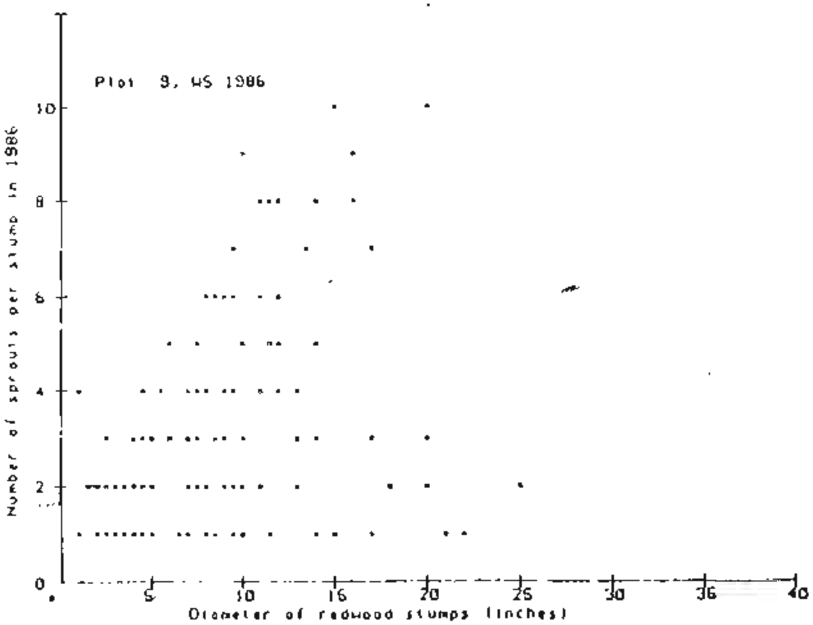
Diameter of old-growth stumps was suggested as a way of determining the level of sprout response (Neal,1967). Whether this is a useful measure to determine potential sprout stocking of cut young-growth trees is not clear. Results show that 90 percent of the young redwood stumps sprouted in the mapped plots (Lindquist,1979). That study did not determine whether the number of sprouts or sprout clumps correlated with stump size. To look at the relation of number of live sprouts >4.5 feet to stump diameter a series of linear regressions of plot data were computed. In addition the data was plotted to see if transformations of the data might prove useful. Linear regression coefficients and correlation coefficients for the six mapped plots are shown in Table 4. Low correlation of number of sprouts to stump diameter in the plots, and visual inspection of graphic plotting of the data indicate that stump diameter is not a good predictor of the number of sprouts at 15 years. No correlation coefficient exceeds .3. The wide variation in number of sprouts for a diameter size (an example,Figure

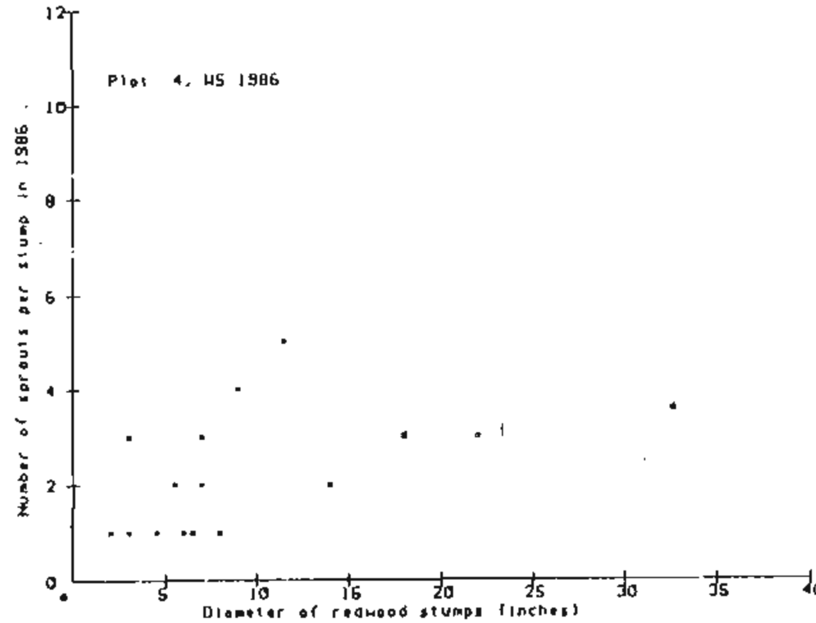
Table 3. Number of sprouts per acre of the 1986 inventory of nine Whiskey Springs thinned plots. Size classes shown the diameter at breast height. Plots 2,3, and 12 were not mapped or inventoried in 1972.

	1972		1986 Diameter classes							
Plot	Clmps	Spts	<.5"	1"	2"	3"	4"	5"	>5"	total
			(number per acre)							
1(25%)	942	6555	472	477	170	65	30	5	5	1225
6(25%)	2022	10835	850	935	350	125	42	10	10	2312
8(25%)	1187	7007	425	665	260	167	58	22	5	1602
9(50%)	1005	4568	528	352	45	5	0	0	0	930
10(50%)	932	5505	565	438	112	18	0	0	0	1132
12(50%)	0	0	438	348	20	0	0	0	0	805
2(75%)	0	0	395	208	18	0	0	0	0	621
3(75%)	0	0	55	35	5	0	0	0	0	95
4(75%)	585	2052	78	10	0	0	0	0	0	88

Table 4. Linear regressions and correlations of the number of sprouts per stump with the stump's diameter of the six mapped Whiskey Springs thinned plots.

Plot	No. stmp.	Ave. Dia.	SD.	Ave. spts.	SD.	slope coef.	intcp. coef.	corr. coef.	SSE
		(in.)							
1	105	10.84	7.03	4.76	2.81	.1254	3.402	.098	2.66
6	264	6.65	5.41	3.51	2.57	.2299	1.986	.233	2.25
8	154	10.46	6.11	4.16	2.97	.1769	2.312	.136	2.76
9	117	8.75	5.26	3.18	2.30	.1491	1.875	.116	2.16
10	113	7.91	5.57	4.01	2.84	.2644	1.917	.269	2.41
4	17	8.32	5.35	2.06	1.25	.1083	1.157	.216	1.07





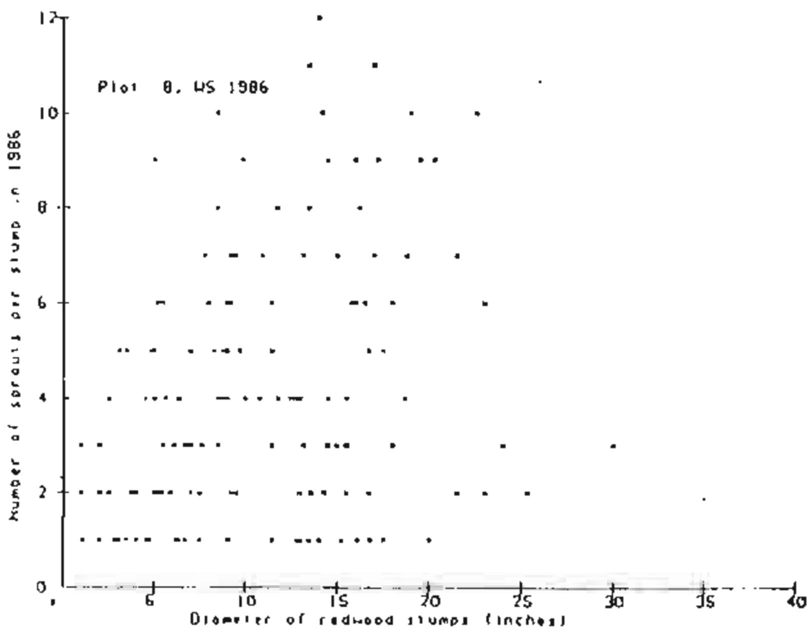


Figure 1. Number of established sprouts sprouts over 4.5 feet tall plotted over the diameter of the stump. Three over-story density levels are represented: Plot 8, 25 percent; Plot 9, 50 percent; and Plot 4, 75 percent.

1) indicate that stump size is not a useful way to determine the number of sprouts in the understory. The standard error of estimated sprouts (SSE) exceeds 50 percent in all the plots.

A previous study of sprouting suggested an idea of one established sprout for each clump tallied in the initial inventory (Lindquist,1974). The relation of the 1986 sprouts to the 1972 clumps is investigated by a linear regression and correlation analysis of the data from the six mapped plots. The following summarizes the results of this:

$$\text{Sprouts 1986} = -362.97 + (1.38505 \times \text{clumps}) \quad (1)$$
$$\text{Corr.coef.} = .925$$

The linear equations variables are well correlated and highly significant despite plot 4 (75% residual), where many sprouts and clumps died and few sprouts exceed 4.5 feet.

This comparison of the number of sprouts established in 1986 with the total clumps numbers in 1972 indicates that for the 25% and 50% treatments one sprout per clump is conservative. The ratio is about 1.16 sprouts per clump. Only in the 75% residual plot 4 does the number of sprouts over 4.5 feet fall short of the rule. Plots 2 and 3 were not mapped so there is no knowledge of the initial number of stumps and clumps, but the 1986 inventory indicates that sprout growth in these plots has not been aggressive. Clearly sprouts are not occupying the space under the crown cover. However there is an overstory that averages over 150 redwood trees per acre, and an aggressive sprout growth has not developed. Restraint of sprout growth by the overstory is an important silvicultural factor that may be used to our advantage. Two conditions may be operative in these dense overstory plots, the inhibition of stump sprouting of by trees in the clumps, and low light levels suppressing growth.

Linear regression studies of individual stump's number of 1972 clumps and 1986 sprouts are shown in Table 5. Highly significant correlation coefficients are shown for all plots except plot 4. However, the SSE of the predicted number of sprouts in all the plots is so great that this amount of variability weakens the usefulness of predictions of number of established sprouts from the initial number of clumps on the stump. The smallest SSE as a percent of the average number of sprouts is in plot 1, 57 percent. All other plots exceed 70 percent, and in plot 4 it is 290 percent.

The effect of residual canopy on the regrowth of sprouts on the stumps is shown clearly in Table 3. Diameters of the largest sprouts decrease as the percent of the basal area residual increases. The three plots of the 25% canopy average 62 trees per acre in the 4-inch and over

Table 5. Linear regressions and correlations of the number of sprouts per stump in 1986 with the number of clumps in 1972 on the stumps of the six mapped Whiskey Springs thinned plots.

Plot	No. stmp.	Ave. clps.	SD.	Ave. spts.	SD.	slope coef.	intcp. coef.	corr. coef.	SSE
1	116	3.31	1.89	4.31	3.02	.8934	1.352	.314	2.49
6	312	2.60	1.63	2.97	2.69	.9649	.463	.342	2.18
8	176	2.70	1.87	3.64	3.10	.9280	1.137	.313	2.56
9	172	2.34	1.47	2.16	2.41	1.2270	-.705	.560	1.59
10	157	2.37	1.71	2.88	3.01	1.2614	-.111	.517	2.08
4	122	1.91	1.36	.29	.85	.1652	-.030	.0700	.81

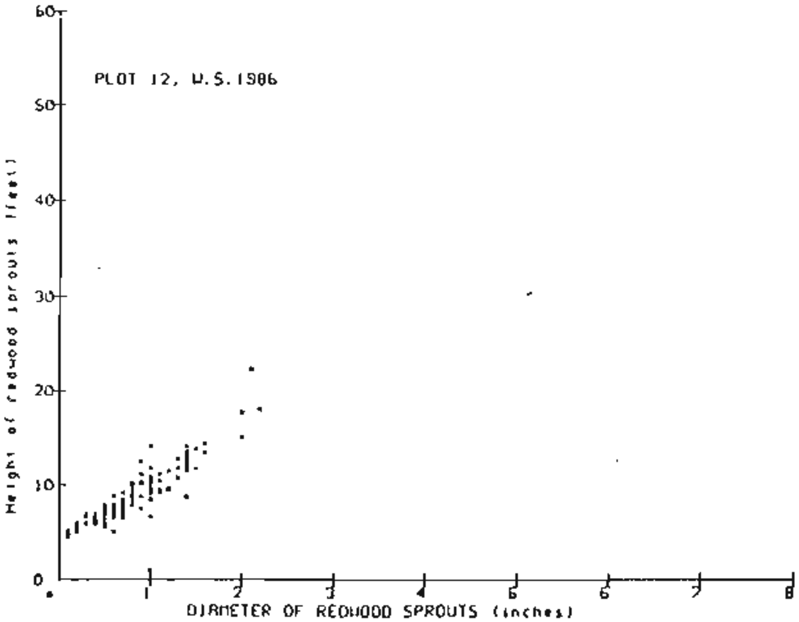
Table 6. Linear regressions and correlations of the total height of the largest diameter sprout on each stump of the nine thinned plots at Whiskey Springs.

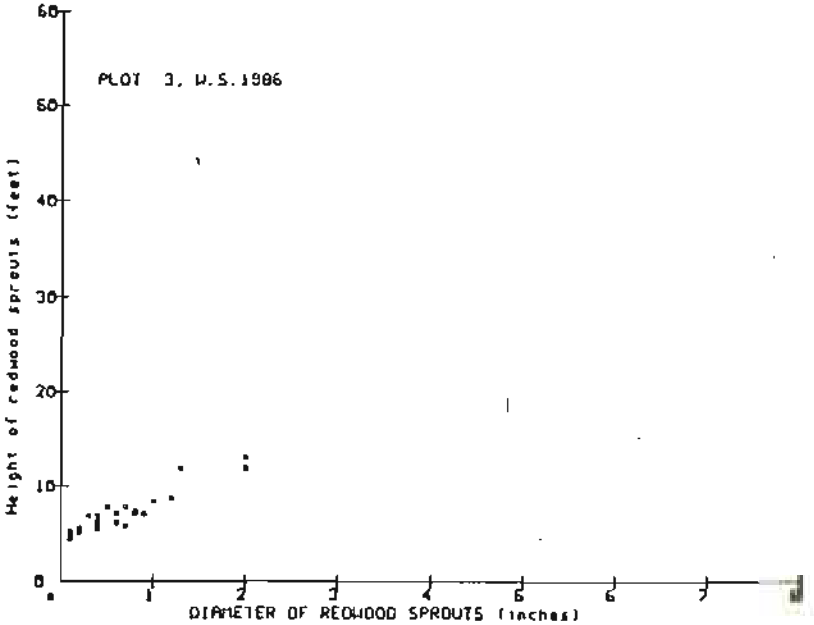
Plot	No. spt.	Ave. dia.	SD.	Ave. ht.	SD.	slope coef.	intcp. coef.	corr. coef.	pred.ht. 1"	2"	3"
		(in.)		(ft.)						(ft.)	
1	103	2.2	1.2	17.6	7.1	5.38	5.95	.87	11.3	16.7	22.1
6	215	1.8	1.2	15.5	7.0	5.69	6.03	.89	11.7	17.4	23.1
8	144	2.4	1.3	20.5	8.9	6.25	5.46	.86	11.7	18.0	24.2
9	116	.9	.6	9.4	3.6	5.58	4.29	.88	9.9	15.5	21.0
10	112	1.1	.7	10.9	4.2	5.77	4.31	.89	10.1	15.9	21.6
12	96	.8	.5	9.1	3.3	6.33	3.78	.85	10.1	16.4	22.8
2	101	.6	.4	8.0	2.6	5.63	4.32	.90	9.9	15.6	21.2
3	28	.6	.5	6.9	2.3	4.06	4.54	.89	8.6	12.7	16.7
4	16	.3	.2	6.0	1.0	5.06	4.55	.91	9.6	14.7	19.7

classes. The 50% plots have no trees over the 3-inch class, and the 75% barely reach into the 2-inch class. Clearly the density of overstory influenced diameter growth. Numbers of sprouts established in 1986 relative to the number of clumps in 1972 in the 25% and 50% plots has not changed much. It appears that the increased crown level of the 50% treatment has not affected the number of sprouts in a manner different than in the 25% plots. It is a different matter in the 75% residual. Only plot 4 in this treatment has 1972 numbers, but it is evident most of the 1972 clumps have not developed sprouts of much value. Only 88 per acre exceed 4.5 feet in height, and only 10 of these reach the 1-inch class.

Similar effects by the level of the overstory canopy on sprout height growth are shown. As many as three of the tallest sprouts on each stump had the DBH and total height recorded. Linear regressions express height as a function of the diameter of the largest sprout on each stump are shown in Table 6; graphic examples are shown in Figure 2. Table 6 also shows the average diameters and heights of the largest sprouts. There are strong linear relations of height to diameter in all the plots. The correlation coefficients are all in excess of .8, these are highly signif-iciant. Both average diameter and height of the largest sprouts increase with the percent of overstory removed. Maximum height of sprouts was 43 feet in the 25% residual, several trees in each plot exceed 4 inches and 30 feet. In the 50% residual maximum size is 24 feet and 3.4 inches, only a few trees exceed 20 feet or 3 inches in diameter. The situation in the 75% residual is that only a few sprouts exceed 15 feet or 2 inches. Regression lines for the treatment levels all have similar height over diameter trends. Predicted heights for a 2 inch tree are: 25%, 17.3 feet; 50%, 15.9 feet; 75%, 14.3 feet. Relation of height to diameter is affected by the crown cover, but the three foot height difference is not as large as expected. Reduced diameter growth under the heavier residual crown cover has an influence on the maximum diameters and heights of the sprouts.

A comparison of quadrat stocking between the number of clumps in 1972 and the number of established sprouts in 1986 is detailed in Table 2. The six plots show that in most instances the percentage of stocked plots has dropped over the period. The reductions are of no real consequence except in plot 4 the 75% residual example. In this plot only 3.5 percent of milacre and 17 percent of the 4-milacre now have established sprouts. While the percentage of stocked plots fell in the 25% and 50% residual plots the actual number of sprouts per acre increased over the number of clumps. Plot 4 fell sharply from 615 clumps to 87.5 sprouts per acre.





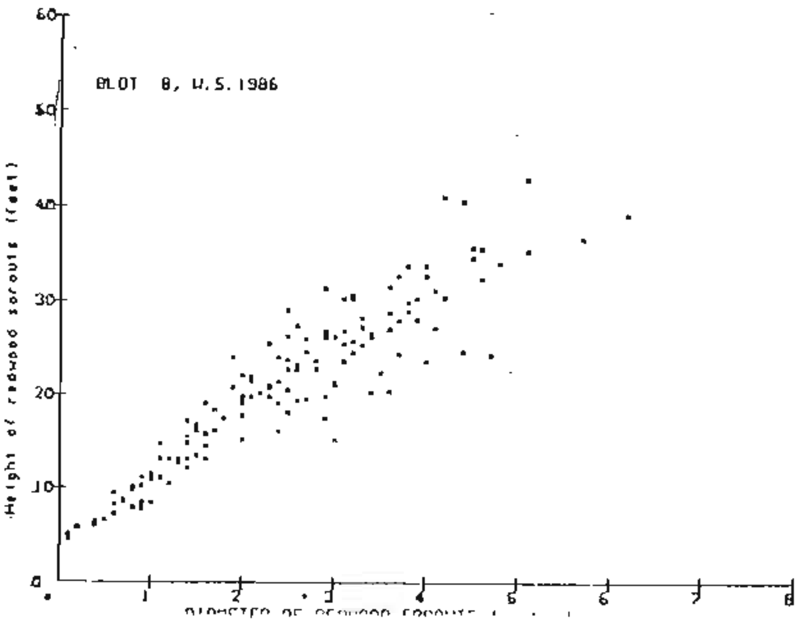


Figure 2. Total height of the tallest sprout over DBH at 15 years of age of the understory of the Whiskey Springs commercially thinned plots. Three overstory densities are shown: Plot 8,25 percent;Plot 12, 59 percent; and Plot 3,75 percent.

Discussion and conclusions

Origin of redwood is seen as important in defining the value of redwood trees since seedlings are purported to have more desirable features (Smith,1962). Sprouts are a significiant factor in reestablishing redwood stands, and it is important that managers have a realistic view of their values and drawbacks. There are problems in dealing with redwood, and the strength of the sprouting capacity is an important one. When redwood is part of the stand most of the stumps will sprout, and the manager cannot economically remove them. Manipulation of stands with silvicultural techniques that enhance or control sprouts is the goal of this study.

Prediction of the number of established sprouts a few years after logging from the initial clump population is a useful tool. It appears that this can only be done on a plot or stand basis. There is evidence that neither stump diameter nor the number of clumps is a good predictor of the number of established sprouts on a specific stump. Regression lines of sprout numbers based on stump diameter or initial clumps are nearly horizontal, and prediction errors are too large. Little confidence can be placed on predictions for a single stump. Prediction of the total plot numbers, shown by equation 1, includes data from plot 4 which had heavy losses and few sprouts grew past 4.5 feet. Recomputation of the regression without plot 4, indicates about 1.13 sprouts per clump, and a correlation coefficient of .945. In this study and a second study of sprouting on the JDSF it was found that 90 to 95 percent of the redwood stumps sprouted when 50 percent or more of the stand was removed; in both studies the plots averaged 2.5 to 3.5 clumps per stump (Lindquist,1987). These examples show that an estimate of the magnitude of sprout restocking can be made before logging from the number of redwood trees. All live redwood stems, regardless of size, need to be counted, since small stumps may have vigorous sprouting.

Results from this study show that the residual canopy exerts a strong influence on sprout development. Initial numbers of clumps and sprouts in the mapped thinned plots were approximately equal. The number that develop into established sprouts over 4.5 feet drops sharply in the 75% residual treatment,i.e., plot 4. Specific information of the number of initial clumps and sprouts in this treatment is limited to plot 4. Table 3 shows few established sprouts in this treatment, and unmapped plots 3 and 4 have less than 100 sprouts in 1986. By contrast the 25% and 50% residual treatments only plots 9 and 12 have less than 1000 sprouts per acre. Of equal importance to the number of sprouts is the vigor and size of the sprouts. Diameter distributions of the sprouts of the thinned plots, shown in table 3, reflects the influence of the overstory density.

In the 25% and 50% treatments the largest diameter classes have an aggressive population whose canopy is closing. Average heights of the largest sprout on each stump (Table 4) for the treatments range from: 17.8 feet, 25%; 9.8 feet, 50%; and 6.9 feet, 75%. There is a highly significant difference (.99 level) in height that expresses the strength of canopy control of growth. This strength of the overstory density to control sprout height and diameter growth offers a mode of control of the sprout regeneration. Most of the sprouts in the 75% plots do not have a robust growth or well defined stem form, few will develop into suitable stems under dense cover.

Overstory density control of resprouting seems realistic. This factor can dictate timing, intensity, and type of silvicultural operations. Precommercial thinning of redwood stands with enough suitable trees, but a canopy several years away from closure may trigger a flush of sprouts on the new stumps. A delay of thinning allows larger stems to close the canopy quickly and restrain growth of new sprouts. Evidence is that removal of 75 percent of the basal area created a unique silvicultural condition. A coppice-with-standards stand develops in sprouting species when a new stand is created under an overstory of a few well distributed prime large stems. Selective logging in the past seldom removed 75 percent of the stand, but similar coppice sprout understory stands with a few large widely separated trees have been created. An aggressive new understory sprout growth of open stands may benefit from precommercial thinning. How to proceed with economically maturing overstory also raises questions that managers need to consider. Should the entire stand be allowed to develop without additional selection logging, or is it economical and productive to log the large residuals despite damage to the new sprouts? How to respond may depend on how well the sprout understory grows. Continued closure of the overstory will adversely affect sprout growth, and it may be wise to remove the overstory. This removal will have to assess the effects of damage to the sprout understory in selectively logging 40 to 50 trees per acre.

A comprehensive view of the commercial thining of the overstory in this study has to consider the growth of the overstory and this new crop of sprouts. The 25% residual plots have a substantial number of sprouts that are now entering the measured stand, and the 25% and 50% plots have well developed understory canopies. The 75% treatment does not lead to a condition of conflict between two canopies. Essentially the lower end of the diameter distribution cut by the earlier thinning is being replaced by new sprouts. The fifteenth year overstory remeasurement indicated that the 50%, 75%, and uncut plots have boardfoot growth that are about equal. Thinning the 25% plots so severly reduced the growing stock that it cannot maintain the capacity of the site. Soon the understory growth will change this growth pattern, and the ingrowth of stems may result in tension in how to deal with the two elements of the stand. This mixture of two distinct canopies with different growth rates has to be understood to determine whether this is a silvicultural option beneficial to owners. Heavy initial sprouting and subsequent sprout growth in the 25% plots under a sparse overstory of large trees may qualify these plots as coppice-with-standards. Boe (1973) mentioned the idea of this silvicultural system for redwood, but pointed out it needs to be tested.

The recent survey in the 50% plots showed that a large number of the initial sprouts survived. Growth of these sprouts has not been as great as the 25% plots, and I feel that as the overstory closes there is the prospect of declining vigor for many of these new sprouts. Except for the most open grown sprouts most new sprouts will stagnate. The prospects for future height growth of plot 12 will look more like plot 3 than plot 8 (Figure 2).

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